Consideration of the relevance of standard quality techniques in Mass Customisation

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Abstract

The business philosophy of Mass Customisation (MC) implies rapid response to customer requests, high efficiency and limited cost overheads of customisation. Furthermore, it also implies the quality benefits of the mass production paradigm are guaranteed. However, traditional quality science in manufacturing is premised on volume production of uniform products rather than of differentiated products associated with MC. This creates quality challenges and raises questions over the suitability of standard quality engineering techniques. From an analysis of relevant MC and quality literature it is argued the aims of MC are aligned with contemporary thinking on quality and that quality concepts provide insights into MC. Quality issues are considered along three dimensions – product development, order fulfilment and customer interaction. The applicability and effectiveness of conventional quality engineering techniques are discussed and a framework is presented which identifies key issues with respect to quality for a spectrum of MC strategies.

Keywords: *Mass Customisation, quality, quality engineering*

1. Introduction

Mass customisation (MC) is an emerging business philosophy and manufacturing strategy. It attempts to combine the provision of customized products and services on a mass scale with operational performance akin to mass production systems. This implies rapid response to customer requests whilst maintaining high levels of efficiency and productivity with limited cost overheads due to customisation (Tseng and Jiao, 1998). In addition, the significant quality benefits that are associated with the mass production paradigm must also be guaranteed in an MC environment. The traditional science of quality deployed in mass production environments is premised on volume production of relatively uniform product specifications. An MC strategy implies significant increases in product variety. However, the processes and technologies to support quality management in MC are immature and quality management frameworks and techniques with respect to MC have received very limited consideration in the research literature.

The philosophy of MC is closely aligned with the fundamentals of quality thinking and quality concepts also provide insights into MC. However, the MC paradigm poses genuine challenges for the discipline of quality management when it comes to the practicalities of controlling and assuring quality to achieve customer satisfaction. The differences between MC and mass production are significant, to the extent that some quality techniques developed for mass production are ill-suited to the MC environment. Furthermore, MC enterprises are different from enterprises that focus on providing pure customisation. Consequently, MC creates a specific agenda for quality management and quality engineering research.

This paper considers MC from a quality perspective and discusses the suitability of existing quality methods and tools for supporting it. The meaning and interpretation of quality concepts are analysed in the MC context and the applicability of existing quality engineering techniques and approaches, both product and service related, are analysed. A framework for the selection of quality techniques, based on fundamental operational modes for MC, is presented.

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2. Mass customisation in the context of quality

MC has the objective of meeting customer requirements (Hart, 1995) and involves the production of customized goods for a mass market (Davis, 1987). MC is often associated with what might be called a 'catalogue MC' mode, in which a product and option catalogue is pre-designed and pre-engineered before being offered to customers. However, the study of companies who consider themselves to qualify as mass customizers and who pass the test of Hart (1995) of customizing any time, anywhere, any way, reveals a richer picture of MC (MacCarthy *et al.*, 2003a). Companies are approaching MC from two directions, one from a mass production heritage and the other from a customisation heritage (Duray, 2002). For the former, the shift can be driven by a need to accommodate powerful and uncompromising customers, and for the latter it is the economy of 'mass' that is attractive (MacCarthy *et al.*, 2003b). MacCarthy *et al.* (2003a) identify five modes, one being the catalogue mass customizer, two modes associated with mass producers shifting into MC and two more associated with customizers increasing their 'mass'.

As noted by Da Silveira *et al.* (2001), a view of MC commonly put forward is that it is a strategy for delivering a wide range of products and services that meet specific requirements of individual customers at a cost near that of mass produced items. Meeting the needs of customers is, of course, the 'raison d'etre' of quality management, e.g. (Fox, 1995). If MC is in tune with the aims of the quality movement, why is MC or a similar concept not heralded in quality texts?

The quality literature is not entirely silent. Kolarik (1995) sees a new quality paradigm emerging - techno-craft - that is MC in another guise. Techno-craft is seen as the emerging quality paradigm, following on from *custom craft*, *mass production and sorting*, *statistical quality control*, and *total quality management*. Kolarik writes: 'The techno-craft paradigm is a new frontier in quality that seeks to emulate the custom-craft paradigm in performance but reduce cost and the delivery time .... In the techno-craft paradigm customers get exactly what they want'. Although there is little evidence of MC being championed by the quality fraternity, it was foreseen by Garvin (1987) in his influential article about competing on quality. Garvin judges that in some situations customers measure quality in terms of the number of features on offer: 'choice is quality; buyers may wish to customize or personalize their purchase'. Without using the term MC he refers to a starter motor manufacturer using the latest in flexible manufacturing technology to customize without having to price its products prohibitively, and he expects this strategy to grow in importance. The argument that customisation falls within the framework of quality is reversed by MacCarthy *et al.* (2003b) who identify quality as one of a wide range of product attributes that are customizable, such as functionality and aesthetics. An expanded list of the customizable attributes is presented in Table 1 and is offered also as a standardised terminology of feature customisation, something which is currently lacking in the MC literature (Tseng *et al.*, 2005). In this paper these attributes are used to appraise the relevance of quality techniques.

In summary, it can be argued that quality philosophies and principles explain to a degree the emergence and growth of the MC strategy.

3. Quality challenges of mass customisation

Some researchers and practitioners have noted some of the quality challenges of MC. Kolarik (1995) sees the new paradigm of techno-craft needing automated and integrated measuring machines. Hassan *et al.* (2000) also point out the challenges of Kolarik's new paradigm, concluding that traditional quality tools appear to be insufficient to cope with advances in technology that support this paradigm, no longer being sufficient to handle emerging needs characterized by customized quality, low production quantity, automated processing, defect prevention at the design stage, and real-time monitoring/diagnosing and controlling of process variations. Massotte and Bataille (2000) argue that future production systems capable of producing many and rapidly changing product variants and product features have considerable implications for the methods and techniques used for monitoring and controlling quality. They consider that small batch manufacturing and imprecise data rule out the implementation of conventional statistical process control techniques and tools. Da Silveira *et al.* (2001) consider quality control and product reliability assessment to be two areas for which research is needed to support MC.

The concerns raised by researchers are echoed by practitioners. Duffell and Street (1999) $describe quality control problems they face in the assembly and testing of customized personal computers and comment on the need for tests to 'be as mass customized as your process'. Burgess (1999) concludes from his experience of short-run manufacturing of products with extensive options and accessories that 'many of the traditional quality tools such as statistical process control, supplier audits and sampling inspection can be of limited value or not cost effective'.

In the following sections the quality challenges of MC are analysed in depth. The appropriateness of common quality techniques to three core processes that occur in any MC environment – product development, order fulfilment and customer interaction – are analysed. These activities are essential parts of the value chain and cover key stages in the lifecycle of a product.

Table 1: Customizable product attributes

Customizable attribute	Description
Dimensional fit/size	Part or all of the product is adjusted, cut or scaled to fit the dimensional requirements specified by the customer
Hardware functionality	The functional capability of the product is altered by changing, adding or subtracting hardware features
Software functionality	The functional capability of the product is altered by changing, adding or subtracting software features, typically by altering or replacing the programming in some part of the product
Property of the whole product	Altering or changing properties that relate to the product as an entity, for example, corrosion resistance, vibration characteristics, noise emission or comfort
Quality grade	This relates to the quality category of a product, such as solid silver or silver plated. There may be objective or accepted standards that define categories or it may be subjective but possibly can be benchmarked. It is probable that altering the grade of a product will also alter another attribute.
Quality level	This concerns measures such as reliability, tolerances, precision
Aesthetics and style	Changing the shape, look or feel of a product, such as by selection of interior décor for a vehicle. Typically colour will fall into this category but colour may also fulfil other customisation requirements such as functionality or personalisation
Identification and personalization	Altering a product by adding a unique identifier for corporate customers or an individual customer, for example, embroidering and individual's name on a garment, adding a corporate logo to a product or altering the colour (livery) of a product
Literature	Documentation is an important part of the product-service package for many consumer and industrial products and must often be customized for the specific product variant, specific market or specific type of customer
Packaging	Many products are differentiated by packaging. Customisation may mean changing packaging design, appearance, physical performance or functionality, but can also mean packing other items with the product

3.1 Quality techniques for product development

The approach to design and the objectives of the design tasks depend on the approach of the mass customizing enterprise. If customers are selecting from a pre-designed catalogue of options, the design function's objective is to optimise design effort. It wants to develop products that have value for customers and that allow those specific attributes to be customized that customers actually want to customize. The design function falls short if customers aren't attracted to the 'core' product or if the customer must compromise on one or more attributes they would prefer to have control over. On the other hand if each product is designed to some extent for a specific customer, then the role of the design task is to fully understand what the customer is seeking and to design a product accordingly. Thus, in product development, the quality issues of concern are:

a) designing for customisation
b) incorporating customer requirements into the design, and
c) assuring the customer's requirements have been incorporated.

An attraction of MC is that a base product can be adapted to the diverse requirements of many customers. From an operations perspective this means that a heterogeneous market can be homogenized. The demand for diversity among customers is captured by the Key Value Attributes (KVA) and the delta Value concepts (MacCarthy *et al.*, 2002). These concepts recognize that customers differ in their perceptions of the product attributes that contribute to value and hence the significance and rank order of attributes can be different from one customer to another. The benefit of customisation is proportional to the degree of differences in the weighting and ranking of attributes across the customer population – a low difference signals low benefit, but a high difference signals a potentially large benefit in providing a level of customisation.

While the KVA and delta value concepts provide insight into the drivers for an MC strategy they are conceptual approaches rather than usable design techniques. Tseng and Jiao (1997, 1998) study the design demands of MC and they judge that it requires a methodology that focuses attention on certain issues more so than generic design approaches such as axiomatic design (Suh, 1990) or TRIZ (Mann, 2001) allow. Tseng and Jiao draw attention to the principles of reusability and the beneficial role of a platform-based structure. Using a power transformer, where the customizable features include power input, power outputs, output protection system, safety approval, thermal performance, product size they illustrate their approach and develop a customizability analysis that links functional features, technical parameters and component assemblies (Tseng and Jiao 1997; Tseng and Jiao 1998; Jiao and Tseng, 2000; Jiao and Tseng 2004).

Capturing the 'voice of the customer' is a challenging task (Tseng and Jiao 1997; Fung *et al.*, 1998). It is a core feature of the House of Quality (HOQ) within Quality Function Deployment (QFD), which provides a structured approach to ensuring that the needs of customers are considered whenever decisions affecting those needs are taken (Chan and Wu, 2002). When fully applied, QFD goes beyond product design, enabling consensus to be reached on the product, process and production requirements to effectively meet the customized quality in a shortened cycle time (Hassan *et al.* 2000). Most texts discuss or illustrate HOQ as a method for finding the *single* best solution to a customer need but what is needed is a method for finding a *customizable set of solutio*ns that satisfy diverse customer needs. An exception is Bamforth and Brookes (2002) but further work on adapting HOQ and related techniques is needed that sets out to capture the 'voices of a customizing set of customers'.

It is probable that a combination of methods should be used in designing customizable products, as proposed by Helander and Jiao (2002) within their agenda for research on E-product development for MC. They argue that the (re)design of a customizable product platform should be an optimal balance between customer needs and the enterprise's design and manufacturing capabilities. They outline a five-step procedure built around market research, conjoint analysis, and product line simulation:

- Survey customer usage and attitudes toward product offerings;
- Collect importance ratings of product attributes based on Analytic Hierarchy Process and QFD;
- Conduct a conjoint analysis to determine consumer preferences for various product features;
- Assess the information content of design with respect to various product features based on the axiomatic design theory; and
- Prepare various product platforms and predict their future market shares from conjoint analyses. At the same time predict the adequacy of the manufacturing capabilities.

A modular architecture is attractive for customized products. It fulfils the reusability principle (Tseng and Jiao, 1998), creating variants by adding, subtracting and interchanging components (Duray *et al.*, 2000) and it allows innovation and development in components to progress independently (Baldwin and Clarke, 1997). A downside of basing a product on combinations of components is that some configurations can be technically impaired by interaction effects. This is particularly the case in electronic products, where product validation becomes a significant quality assurance task as illustrated by a computer assembler (Holliday, 2001). A new version of a component often enters the product range at the premium end and tends to be sold in computers with other higher priced components only. However, within a matter of months the component becomes 'standard' and the number of components it could be installed with grows. Consequently, validation of the component continues over its life, with it being first tested and released for use with a limited number of components and then being further tested with an increasing range of components. A challenge for the assembler is to reduce the burden of validation testing by anticipating from the results of the interactions tested for so far, the untested components with which it will or will not suffer interaction problems.

Modular and highly configurable products can generate huge variety in parts and specifications. Forza and Salvador (2002) describe the quality problems in a company which had tried to 'normalise' its designs but would further engineer the product if customers required it. Without an appropriate information system, i.e. a configurator, the task of preparing a BOM for each order was time consuming, checks tended to be omitted due to workload, and errors often were detected as late as the assembly stage, sometimes resulting in substantial delays. Careful development of a parametric product model within a product configurator reduced the need for new engineering, increased the correctness in the specification, and improved delivery timeliness.

A further quality objective for the product development stage is to assure that the customer's requirements are being incorporated correctly into a product and that the design solution will actually satisfy the customer. Various techniques are available for assessing and testing a design against a specification, such as failure modes and effects analysis (FMEA), reliability block diagrams, fault tree analysis (FTA), task analysis techniques, and a raft of techniques such as hazard and operability analysis (HAZOP) that have been developed for particular circumstances. These methods focus on quality level and function and to some degree whole product properties. They are not suited to addressing the customizable attributes of aesthetics and style, dimensional size/fit, personalization, or quality grade identified in Table 1 that can have a subjective element. Involving the customer actively in reviewing the product is the most reliable tactic in these cases, but is not straightforward.

One approach to involving the customer is to give them the bill of materials (BOM). This may make the customer comfortable with the quality grade of the product, since this attribute is dependent, to a degree, on the grade of components. A similarly crude approach is to pass product drawings to the customer for them to confirm the size and fit conforms to their requirements. Both approaches place demands on the customer and can be acceptable and helpful if the customer is a professional buyer, especially if drawings are generated as the customer interacts with an product automated configurator (Forza and Salvador, 2002), but when dealing with individual consumers such methods may be impractical or inappropriate.

A superior way of tackling the dimension attribute is to make a (scale) model or prototype of the product. It is a method that suits also the review of the aesthetics and style of the product and how any personalization is executed. Whereas models and prototypes were once made of clay or similar, developments in the technologies of rapid prototyping and virtual reality (VR) are opening up new options. Ottosson (2002) describes VR as offering 'an accurate and detailed method of communicating concepts to the first customers/users' and notes that it is good for aesthetic and ergonomic design aspects. He reports a case of using VR in the development of a passenger vehicle in which 'textures, colours, lighting, etc. were added to get a real feeling of the new car'. A purchaser could walk around the car, open the front door and even start the wipers to see and experience the design idea from the driver's position. One issue Ottosson reports as not yet resolved is the automatic re-conversion of VR files into CAD files, leaving the CAD data to be changed manually to comply with alterations made in the VR view.

In the context of shoe design, different formats of VR including a physical "foot glove" as well as imaging are in development (Vigano *et al.*, 2004). The customer puts on the "foot glove" which simulates the feel of the shoe. Together these techniques are supporting several customizable attributes including fit, aesthetics and style, and properties of the whole product (such as weight and suppleness).

3.2 Quality techniques for order fulfilment

The role of the order fulfilment function is to manufacture the product and deliver it at the required time to the correct person and or place (Shapiro *et al.* 1992). The literature indicates that the order fulfilment process is becoming increasingly challenging in respect of controlling and monitoring quality and that very high levels of variety, small batches and customized quality standards are a spur to embed quality control into the order fulfilment process management system.

With the consequential growth in variety that MC implies, the philosophy of 'Design of Experiments' (DoE) applied to product or process factors is attractive in order to make product quality robust to variation (Ferguson and Dale, 2001). DoE may provide a methodology to 'immunise' quality from this variation but on a practical level, as the number of customisations grows so does the number of potential experimental conditions, with implications on resource demands.

With respect to statistical quality control methods, the arguments are that changes in the manufacturing environment are reducing the opportunities for their application. The shift to higher variety and smaller batch sizes is observed generally in manufacturing. An illustration is given by McDermott *et al.* (1997) who examine the changes in power tool manufacturing over three decades. Hassan *et al.* (2000) state that it is difficult to apply traditional SPC charts efficiently and effectively to low volume production as insufficient products are produced to establish control chart parameters. They suggest this limitation can be overcome by focusing on the process characteristics rather than the characteristics of the product itself. Other approaches they note include the use of the deviation from nominal (DNOM) control chart, CUSUM control chart and exponentially weighted moving-average (EWMA) control charts, which detect shifts more quickly than standard chart types.

Massotte and Bataille (2000) also consider conventional SPC techniques and tools to be inappropriate for small batch and one-of-a-kind manufacturing unless products share common features and use the same processes, in which case there is opportunity to attain acceptable sample sizes. They call this feature-based sampling (and they argue that the concept of *product* has to be replaced by the concept of *feature-based production system*). However, they go on to say 'as interaction and dynamics apply in such systems, independence of variables and parameters is not obvious and the traditional statistics used for designing sampling plans have to be reconsidered'. The authors refer to work to develop control charts for small batch control that are like Shewart charts but use the CUSUM method. Practitioner experience also backs up the reduced relevance of statistical methods (e.g. Burgess, 1999).

However, it is wrong to assume that high variety will eliminate repetitive tasks from all forms of MC. The delaying of product differentiation (known as postponement) and the related tactic of commonality, are often cited as principles to design MC operations to prolong 'mass' processes (e.g. Feitzinger and Lee, 1997; Pagh and Cooper, 1998; van Hoek, 2001). An example used by Lee (1996) of how postponement can reduce inventory also shows how it can maintain 'mass' quality tests. The example involves the testing of a computer hard disc drive. Postponement is achieved by delaying the fitting of a customized circuit board to each drive by attaching instead a 'coupon' circuit board. Although this adds steps in the process, i.e. insertion and removal of the coupon board, it creates repetitive quality tests to which statistical monitoring techniques can be applied.

Even with postponement being practised there will be differentiation and high variety at some point. An example of a computer assembler supports the belief that the quality system can be integrated with the production control system. Duffell and Street (1999) describe how quality tests must be tailored to each computer's configuration and therefore the tests must be mass customized along with the product. A quality test file is created and used by the central process control system, into which the assembled computers are connected, to trigger and monitor function tests and burn-in cycles, which are dependent on the BOM.

One consequence of higher component variety is that there is less opportunity to build a performance history. This raises difficulties in interpreting life-testing results and 'infant mortality' rates. If a component is seldom used, the random occurrence of failures makes it uncertain as to whether the failure is indicative of a fundamental fault or a spurious event. Warranty data could assist and Burgess (1999) advises that 'documenting all warranty related calls and performing failure analysis on returned product is essential if the overall quality management strategy is to be successful'. He recommends warranty information and complaints be 'organized in a database and regularly reviewed for trends'. However the reality can be that information on faults from the field are difficult to interpret. Holliday (2001) comments that whereas failures in manufacturing are investigated and reported methodically, field failures are not and so have low validity since there may be less precision about how well a cause has been diagnosed, especially if the product is serviced at the customer's site.

The computer assembler provides an example of function testing being used extensively, with all products tested at several stages along the process (Duffell and Street, 1999). Function testing is a form of inspection, and although the quality doctrine is to do away with inspection by preventing errors or faults, this is not the only instance of a company integrating function testing into a high variety process. The approach is fairly common in consumer electronics manufacture. A mobile phone handset manufacturer is doing the same, not only to catch defects but also to check that the configuration matches the customer's specification (MacCarthy *et al.*, 2003b).

The mobile phone facility provides another insight into quality challenges of order fulfilment for MC. One handset could have several hundred variants. Many are software customisations but still a high proportion is component customisation. It is standard practice for the BOM and assembly plan of a new variant to be checked carefully by a manufacturing engineer and for a single handset to be sent through the process as a trial build before the new variant is released. Experience has taught the company that small changes in configuration or new components could halt the automated line.

A phenomenon observed in recent years is a trend away from automated assembly lines to manual operations, with flexibility and agility being the motivation. The use of mistake-proofing (Poka Yoke) can be expected to be a quality technique that is built into the product and process design (Shingo, 1986). Tozer (2003) provides an example of using different component interfaces between mass customized ranges of office seating, such that arms and other components cannot be intermixed. Otherwise no mistake proofing is used and he reports mis-configurations being a minor contributor to the manufacturing quality performance of less than one percent of items with problems.

3.3 Quality techniques for customer interaction activities

An objective of customer interaction activities is to understand and verify the customer's requirements and to ensure that the customer's expectations of the enterprise are valid and can be accommodated. When viewed from a quality perspective, there is more to customer interaction than the collecting of factual information about 'what' product the customer is seeking, 'where' the customer wishes the product to be delivered, 'when' the customer wishes the order to be fulfilled, 'who' the order is for, 'how many' of the product is being ordered. Treating customer interaction as a process of communicating order related information misunderstands the crucial role it plays in business performance. The need for mass customizers to increase their contact with customers brings them into the realm of service design. This is one of the fundamental changes that manufacturers who move into MC need to appreciate and respond to (Helander and Jiao 2002).

In general, service encounters have a high impact on customers; the quality of the encounter being an essential element in the overall impression and evaluation of the quality of service (Lewis, 2001). For mass customizers the challenge lies in designing the service encounter to encourage purchase and in monitoring satisfaction with the process.

The development of quality techniques for designing services is not as developed as for product and process quality. An indication of this is the lack in standard quality texts of lists of service related techniques similar to the lists given of techniques for product design and manufacture. Harvey (1998) provides a description of techniques, including several summarised below.

Techniques for service design

- *Scripted interactions*. If there is sufficient certainty in how the service encounter can unfold, scripts can be used to achieve consistency. Product configurators are a form of scripting - they control the information flow to the customer and their sequence of choices (as illustrated by Forza and Salvador, 2002);
- *Boundary positioning* is concerned with the 'line of visibility' and the 'line of accessibility'. The first delineates what the customer can see, the latter what they can participate in;
- *Customer involvement* is the extent to which a customer participates in the service creation and delivery process;
- *Failsafing* is the application of the mistake-proofing principle to customer interactions, e.g. removing choices from an interactive web-based questionnaire to prevent customers picking incompatible or unavailable options;
- *Blueprinting* is an approach to mapping and analyzing the service delivery process, taking account of where customers interact with the service provider, how the service encounter links to back-office activities and how management processes interface with the delivery processes.

Techniques for monitoring the service process

- *Customer satisfaction measurement*. Measurement tools and techniques have been developed for services. A notable version is the SERVQUAL approach, an instrument for quantifying the service expectation-perception gap along five generic dimensions (Parasuraman *et al.*, 1988);

- *Critical incident analysis* examines the episodes in service encounters that customers recall as being strongly positive or negative;
- *Mystery shopping.* This is an approach for letting service providers see their services as customers see them. Anonymous professionals or trained customers test various aspects of a service and report on their perceptions. The mystery shopper can follow a script to check conformance or rate various aspects of the service;
- *Close-out reports.* Once an order has progressed past a milestone a retrospective assessment can reveal improvement opportunities;
- *Complaints analysis.* Although care must be taken in interpreting the frequency of complaints due to the unwillingness of many customers to register their dissatisfaction, they can provide a rich source of information;
- *Statistical methods.* The statistical methods developed for product / process control have been applied to services to monitor such factors as time to serve customers and proportion of customers fulfilled.

Silvestro (2001) concludes from her study of three service organizations that service design should be contingent on service type and setting. There are indications that a contingent approach should be taken to the design of the customer interaction process for mass customizable products, with contingent factors being a combination of customer factors – such as customer knowledge of the product - and product factors, such as complexity of the product, type and number of options.

The pool of research into consumer behaviour is vast and it can be expected to hold many lessons for MC. Consumer research includes studies on issues pertinent to MC, such as the implications of novel (Mukherjee and Hoyer 2001) or common product features (Chernev 2001) on consumer perceptions, and research into the underlying psychological mechanisms such as how emotional responses influence consumer decisions that involve trade-offs (Luce *et al.*, 2001) that are a core part of the customisation process.

Research that addresses directly how the customisation process affects consumers is emerging and is summarized in Table 2. The number of studies is small but is replete with warnings, such as that the complexity of the configuration process may confuse consumers, and that there is a danger that a computer based configurator interface will be perceived as offering fewer alternatives through its menus than would be found on the shelves in a shop, even though in reality there can be several orders of magnitude more. The pitfalls are summed up by Godek *et al.* (2001), who conclude from their experiments that 'contrary to popular belief, customisation may lead to … lower levels of satisfaction, and a lower price that decision-makers are willing to pay for the customized alternative they select'. However, there are encouraging findings, such as the tendency for more options to be selected when care is taken over the bundling of types of options and how they are offered (Hamilton and Sivakumaran, 2002).

Further evidence of the complexities of consumer behaviour emerges from the research into how to involve the customer in the customisation process. One method is to involve them actively and the other is to anticipate their preferences and offer them the finished product. Godek *et al.* (2002) examined the two methods and concluded that the preferred method depends on how well the consumer understands the product, and that the appropriate match between method and customer increases satisfaction. On the surface this indicates a mass customizer should identify the category in which their product and customer belongs and select the appropriate method. However, the research of Bendapudi and Leone (2003) adds a twist to the issue. They conclude that involving customers can result in them being more satisfied overall but at the same time make them less appreciative of the customizing enterprise since they tend to attribute the successful outcome to their own part in the process. If the customer had been as equally satisfied by an enterprise using a predictive strategy the enterprise would receive greater appreciation. If customer loyalty and repurchases are critical to the enterprise the implications of these findings may be significant.

Self-service technologies can be expected to be part of the service delivery process for mass customized products, if only to lower costs. Self-service technologies have been around for some time - food vending machines, automated teller machines, ticket dispensers – and are on the increase with the development of voice activated telephone services and web-based shopping stores. However, research into the design of self-service technologies, particularly from the perspective of customer satisfaction, is limited (Meuter *et al.*, 2000) and research and guidance on how to design interactive web-sites to enable consumers to participate in the design of their customized product is awaited (Helander and Khalid, 2000).

Table 2: Summary of consumer research related to Mass Customisation

Reference	Research issue	Context	Findings
Huffman and Kahn (1998)	Differences between attribute-based and alternative based choice presentation and level of consumer effort in the choice	Comparison of sofa configuration and hotel selection	For high variety assortments, the attribute-based format reduces perceived complexity, increases satisfaction with the process and facilitates consumer willingness to make a choice
Godek *et al.* (2001)	How the method of presenting customisation can influence consumer decisions making	Configuring pre-packaged sets of sports tickets; selecting computer configurations	Customisation may lead to perceptions and consideration of fewer alternatives, lower levels of satisfaction, and a lower price that decision-markers are willing to pay for the customized alternative they select, relative to decision-makers in non-customisation conditions
Hamilton and Sivakumaran (2002)	The effect of constraining choice, in the form of option bundles, on customer satisfaction	Choosing options for three products: a car, computer and an apartment. Options were hedonic or utilitarian	In general satisfaction is lower when options are bundled than when selected individually. However, in some conditions satisfaction was greater when hedonic options were bundled with highly justified utilitarian options. In addition, making bundles of options available in addition to individual options significantly increased the number of options selected.
Godek *et al.* (2002)	Situations when a customisation or personalization presentation method should be used	Pizza selection (a task participants felt they were better able to match their preferences) and air travel (a task participants felt the firm was better able to match their preferences)	Customisation was preferred when the product was one that participants felt capable of identifying the product that best matched their preferences. For products that the firm was felt to be more capable of identifying a best match, personalization was preferred.
Diehl and Zauberman (2002)	The influence of presenting a product in a personalized manner on consumers' perceptions of the retailer and merchandise	Search and selection for an electronic birthday card	Sequence of presentation and freedom of terminating the search influence perceptions of the retailer and of variety and quality of merchandise

4. Discussion

The analysis and review has focused on the issues in, and the techniques to support product development, order fulfilment and customer interaction for enterprises offering Mass Customisation. The importance of leadership, continuous improvement, elimination of waste and other factors that are part of a rounded Total Quality Management approach is not investigated. Therefore, in questioning whether MC poses practical quality challenges, as suggested by Kolarik (1995) and others, this paper is not attempting to validate the claims of Kolarik (1995) of a new emerging paradigm in the field of quality. It is the expectations of limitations in traditional quality tools and the need for integrated approaches to quality that are of interest here. The indications are that there are shortcomings in conventional approaches and that some MC operations can function only with integrated and automated quality tasks.

The pool of experience and literature that addresses MC quality issues is limited. Hence a caveat must be placed on this conclusion. There are examples where integrated and automated inspection or function testing are mentioned as being critical (Kotha, 1995; Duffell and Street, 1999) but there is also an example of MC being implemented without recourse to such complexity (Tozer, 2003). The experience is also limited in regard to the range of customizable attributes that are being mass customized, hence expectations stated here, such as of mass customizers using rapid prototyping or virtual reality if they customize dimensional or aesthetics in particular, are logical deductions that can be supported by a few cases but as yet cannot be substantiated empirically.

As well as being a multi-dimensional concept, customisation is dynamic. For many consumer products customisation is continually changing - markets change, tastes and fashion change, material and production technologies change. It is likely that such temporal variation will create quality challenges in addition to the problems of coping with product variety and customer differences that exist at any specific time. The evolution of markets over the last decade, with many sectors experiencing more competition, more variety and more market segmentation, is one reason for interest in MC growing (Cox and Alm, 1998; Bils and Klenow, 2001), but it cannot be expected that a mass customizable product or the order fulfilment and customer interaction processes that support it can fully mitigate such changes. Given that MC is in its early stages as a business paradigm and manufacturing strategy, MC researches and practitioners have yet to turn to formulating and operationalising *sustainable* MC strategies and tackling the quality challenges within. Below we present a framework for considering and selecting quality techniques and approaches in different MC scenarios.

5. A Framework for the selection of quality techniques for Mass Customisation

Not all quality techniques are pertinent for every MC application. The customizable attribute(s) will have a bearing on the choice of technique(s) and, fundamentally, the selection of techniques can be expected to be contingent on the approach being adopted for MC – the MC operation mode. For the purposes of developing a quality framework, the five operations modes identified by MacCarthy *et al.* (2003a) are compressed into three modal categories – Catalogue MC, Call-off MC and Design-per-order MC – defined below:

- *Catalogue MC*: A customer order is fulfilled from a pre-engineered catalogue of variants/options. Orders are fulfilled using processes that have been engineered ahead of an order being taken;
- *Call-off MC*: A customer order is fulfilled by engineering a customer specific product. The amount of engineering may be extensive. There is an expectation of (and requirement for) repeat orders, and the customer can order the product at any time in any volume to as low as a single unit. For some enterprises the order fulfilment resources are fixed, which places constraints on the product design, but some MC enterprises may be prepared to modify order fulfilment resources to satisfy specific customisation requests;
- *Design-per-order MC*: A customer order is fulfilled by engineering a customer specific product. The amount of engineering can be extensive. For some enterprises the order fulfilment resources are fixed, which places constraints on the product design but some enterprises may be prepared to modify their resources. There is no expectation of repeat orders.

It is not argued here that there are hard and fast rules as to when quality techniques are used by enterprises following an MC strategy. However, it is expected that certain techniques will suit one mode more so than another. The framework, summarised in Table 3, links quality techniques to the modes based on an appreciation and expectation of there being common characteristics in the market environments in which a mode is employed, and different characteristics in place for different modes.

The view that the MC mode is contingent on the business environment is put forward by MacCarthy *et al.* (2003b) based on case study evidence. As well as the market requiring product variety, they identify two environmental factors that influence the choice of mode: the strength of customer need or desire for uniqueness or differentiation from other customers, and customer power. They argue that Catalogue MC is most suited to circumstances in which there is a low desire for diversity in the product range and low customer power. In these conditions the enterprise has scope to plan and control the variety in its product range. With respect to quality techniques for product design, Catalogue Mass Customizers can benefit from a structured method of analysing the variety required in the marketplace and can pay attention to designing a customizable platform. A modified form of Quality Function Deployment, probably in conjunction with other techniques such as those proposed by Helander and Jiao (2002) is likely to be suitable. Of the three modes, this is interpreted as the one where the enterprise has the greatest control over the rate of change of the product, and it offers the opportunity to design the product's architecture to suit present and future customisation. Product change management will be an important competence, especially if the product is benefiting from technological advances or is prone to fashion trends. The ability to plan and control product design creates opportunities to control the design of the order fulfilment process also and hence, of the three modes, this is the one where experimental methods are most likely to be used to optimise process parameters and it is also the mode where mistake proofing is most likely.

Table 3: Quality technique framework

<table>
<tr><td colspan="2" rowspan="2"></td><th colspan="3">Mode</th></tr>
<tr><th>Catalogue MC</th><th>Call-off MC</th><th>Design-per-order MC</th></tr>
<tr><th rowspan="3">Core Process</th><th>Product development</th><td>Modified QFD
Validation / Change control</td><td colspan="2">QFD
Rapid Prototyping
Virtual Reality
Critical incident analysis
Close-out reports</td></tr>
<tr><th>Order fulfilment</th><td colspan="2">Design of Experiments
Mistake proofing
Integrated quality tests
Statistical methods
Warranty tracking
Complaints tracking</td><td>Critical incident analysis
Close-out reports</td></tr>
<tr><th>Customer interaction</th><td>Scripted interaction
Boundary positioning
Customer failsafing
Mystery shopping
Customer satisfaction surveys
Statistical methods</td><td colspan="2">Customer involvement
Critical incident analysis
Close-out reports</td></tr>
</table>

The principle of delayed differentiation can be expected to be most prevalent in this mode compared to others, and hence statistical process control techniques are also expected to be relevant and used most frequently here. As this is the mode with the most repeatability, the monitoring and analysis of warranty claims and complaints can be expected also to be prevalent. In regard to customer interaction, this is the mode in which there is greatest certainty in anticipating the wishes of customers since the product range is controlled by the enterprise. In the other modes customers may propose unexpected modifications or designs. The relatively greater certainty enables a Catalogue customizer to apply techniques such as scripting and customer failsafing (especially if an interactive web-based configurator is used) and pay careful attention to boundary positioning. Statistical methods could be used for monitoring performance of the interaction processes along with mystery shopping and customer satisfaction surveys.

The design-per-order MC mode suits a market environment where customers want or need uniqueness or differentiation and the order volume is very low. An example of this is steel fabricated bridges, such as walkways over roads, where each site can have unique requirements but where common elements can be incorporated into the design, such as in standard runs of steps. Here there is some scope for using structured methods like QFD to understand the market's acceptance and need for reusable elements, but other approaches must be used to elicit customer's needs. Rapid prototyping and Virtual Reality are expected to be favoured by enterprises in this mode more so than those in the other modes. Due to the uncertainty of the customers requirements, the order fulfilment and customer interaction processes need to be flexible. This limits the use of pre-planned methods such as statistical quality techniques or interaction scripting. Of the three MC modes the Design-per-order mode will be the one where enterprises rely most on learning lessons from how orders were handled, from the design stage through to delivery and into after sales support. Consequently, critical incident analysis (Edvardsson and Roos, 2001) and close-out reports can be expected to be used.

The Call-off MC mode lies between the two other modes. Examples given by (MacCarthy *et al.*, (2003a, b) of enterprises conforming to this mode are a bicycle manufacturer and commercial vehicle manufacturer both of which are entering the mass customizing strategy with a mass production heritage. It is reported that both organisations have some powerful customers - large retail chains wanting distinctive products in one case, fleet buyers with different needs in the other case. None of the quality techniques discussed above is expected to be of greater relevance to this mode than to the other modes. In regard to order fulfilment, Call-off MC is expected to be more similar to Catalogue MC than to Design-per-order MC, but for the other two processes it is expected to be more similar to Design-per-order MC.

6. Conclusions

This paper has analysed MC from a quality perspective. It is argued that MC is a natural consequence of quality ideals since its goal is to provide all customers with the product they want. The review of quality methods for MC has focused on the suitability of techniques for MC operations, including product development, customer interaction and order fulfilment activities. The paper has presented a framework for considering and selecting quality techniques and approaches for different operational modes of Mass Customisation.

Recent literature is adding to the understanding and mapping of the MC domain and this has been used in the review. It is informative particularly to consider quality control and quality assurance demands in relation to different forms of product customisation and to different operations modes of MC. It is argued that the quality techniques employed by a mass customizer will be contingent on the product attributes being customized and on the commercial environment in which it is operating.

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